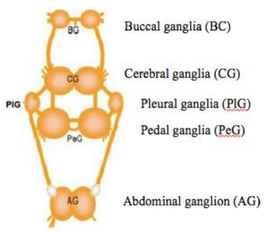
Control neuron activity with miniature magnetic coil – theoretical and experimental study

Lauryn Barrett, Jessica Helon, Hui Ye
Department of Biology, Loyola University Chicago

Introduction

Direct neural control has been used in varying clinical practices, such as deep brain stimulation, however, shortcomings, like biocompatibility, need to be addressed. Recently, miniature-sized magnetic coils have been used to activate selected neuronal subpopulations. The miniature coil can be covered with a biocompatible material, which prevents the direct contact between the electrode and neural tissue, eliminating numerous problems that may arise at the brain-electrode interface. However, the cellular mechanisms of single neural activation by the miniature coil is largely unknown. We address this question by investigating the activation of large neurons in the buccal ganglion of Aplysia californica under miniature coil stimulation.

Previously in Dr. Ye's lab, a miniature coil showed promise in activating action potentials when recorded from the nerve (figure 3). Using a modified NEURON model we have found that a miniature coil can initiate action potentials in the soma which propagate down the axon. Preliminary in vitro data shows that single magnetic pulses can elicit action potentials in the soma.



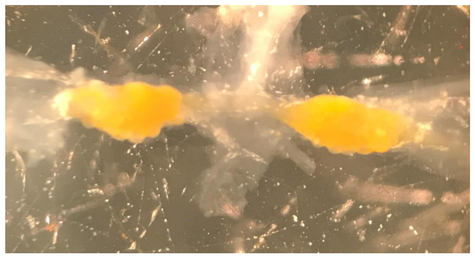


Figure 1. *Aplysia californica, their central nervous system, and their buccal ganglion.*

Question

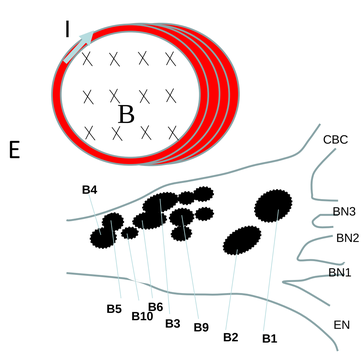


Figure 2. Can magnetic field elicit action potentials by stimulating the soma with the coil positioned over the buccal ganglion? With the current (I) flowing clockwise and the magnetic field (B) going into the dish.

Preliminary Data

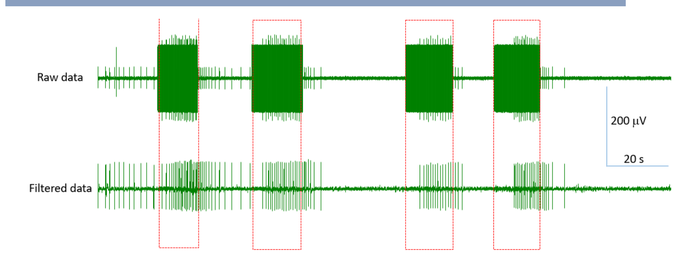
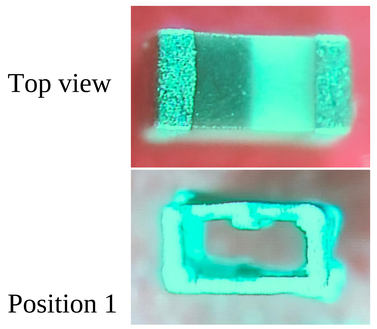


Figure 3. Magnetic stimulation on the soma elicits action potentials. 400 Hz pulsed magnetic stimulation on the buccal ganglion elicited action potentials, which is recorded in the buccal nerve II. Suggests activation of the whole ganglion.

Background



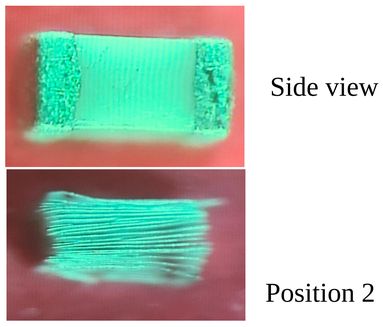


Figure 4. The coil is 1mm x 0.5mm x 0.5mm, about the size of the tip of a mechanical pencil. It is covered in a ceramic coating (top & side views) When the coating is dissolved in hydrofluoric acid, a stack of coiled wires is revealed (positions 1&2)

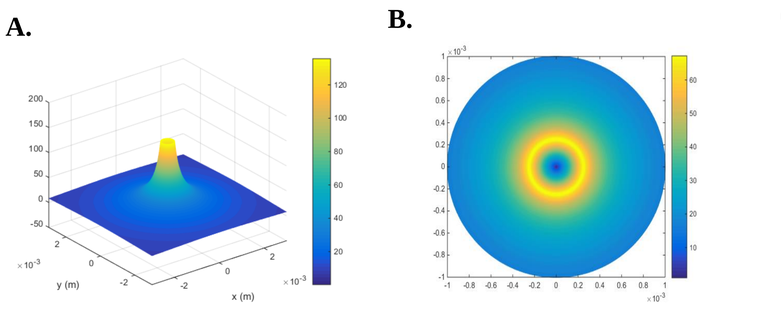
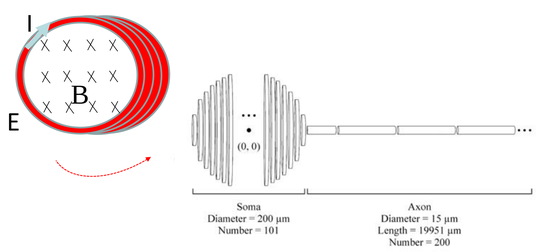


Figure 5. Computation of induced electric field around the mini coil **A.** Intensity of the induced electric field inside and outside of the mini-coil in 3D space. Color map plot for the field intensity and its distribution around the coil, with the brightest, most intense induced field being inside the coil. **B.** Intensity of the induced electric field inside and outside the mini coil in 2D space. With the same color distribution as in [A]. **C.** The intensity of the electric field (in V/m) compared to distance from the coil center. The peak is inside the coil, while the ganglion will experience intensities between the 2 blue lines. Each color graphed represents a different stimulation intensity.

Results

NEURON model simulation



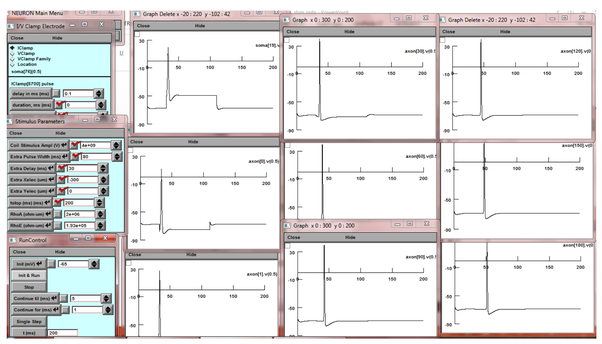


Figure 8. NEURON simulation with the coil over the soma producing a 4e+09 V pulse can produce action potentials in the soma. The action potentials propagate down the axon over time.

Magnetic stimulation on the soma initiates action potentials

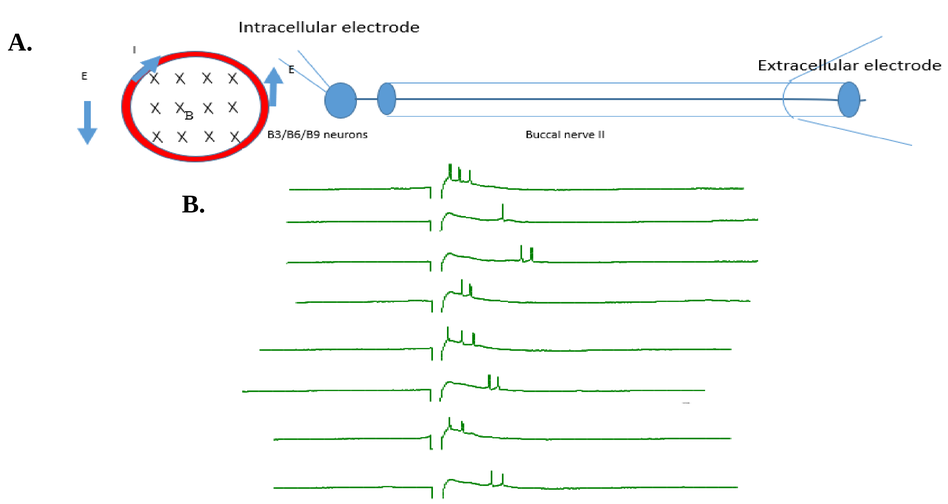


Figure 9. A. The coil is positions over the soma with an intracellular recording electrode and an extracellular, suction recording electrode. **B.** 30 ms duration, 1 Hz stimulation by the coil elicited action potentials in a single ganglion neuron.

NEURON Modeling Parameters

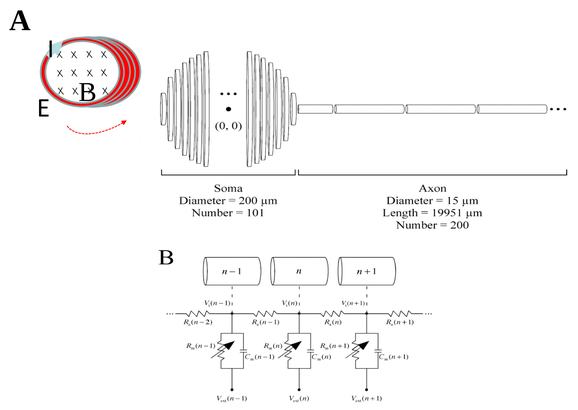


Figure 6. A. Multicompartment model for magnetic stimulation modified from Lu 2008. The soma is composed of 101 segments whose center is at (0,0). The axon is composed of 200 segments and reaches 19951um. The coil is positioned over the soma (not to scale). **B.** The passive neuron properties used in the axon as described in Huxley 1952.

Methods

Buccal ganglion isolation: *Aplysia californica* ranging from 150 to 200g were anesthetized using dissection solution (.333M $MgCl_2$ $6H_2O$), and the buccal mass was dissected out and immersed in *Aplysia* saline (.460M NaCl, .055M $MgCl_2$ $6H_2O$, .011M $CaCl_2$ $2H_2O$, .01M KCl, and .01M Hepes). The buccal ganglion was isolated, and the nerves of the ganglion were stretched out and secured into a glass. The buccal ganglion was stored in 4ºC for 30 minutes prior to beginning electrophysiology experiments.

Electrophysiology: Extracellular recordings were performed with a suction electrode by releasing one of the buccal nerves and suctioning it into the tapered end of the electrode. Intracellular recordings were preformed by inserting a glass electrode with an opening roughly the size of the soma into the soma. The other end of the electrode was connected to an alternating current (AC)-coupled differential amplifier that recorded neural activity.

Electrode preparation: Glass electrodes were pulled from single-barreled capillary glass using a Flaming-Brown micropipette puller. Extracellular electrodes were pulled at a single higher heat. Intracellular electrodes were pulled at heat 1 then 2.

Magnetic stimulation: 1 Hz, pulse magnetic fields were delivered into a miniature coil on the buccal ganglion (above the B3/B6/B9) neurons.

Conclusions

- Modeling suggests that magnetic stimulation on the buccal ganglion can create action potentials and cause them to propagate down the axon
- Magnetic stimulation on the buccal ganglion can elicit action potentials recorded in the soma.

Future Directions

- Collecting more data to support the in vitro model
- Finding a correlation between soma and nerve activity
- Developing the thresholds for activation

References

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Acknowledgments

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